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Material Optimisation for Nanoparticle-Sensitized Radiotherapy

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Abstract

Purpose:

To evaluate the potential applications of nanoparticles of different elemental compositions as X-ray radiosensitizers.

Methods:

Geant4 Monte Carlo models were used to model the interactions of 10 nm radius nanoparticles of elements ranging from silicon to mercury with either monoenergetic keV X-rays or a 6 MV Linac spectrum. Secondary electron spectra emitted from nanoparticles and resulting radial doses were calculated. Potential biological impacts were evaluated through the use of the Local Effect Model.

Results:

For keV radiation, fluorescence photons and energetic photoelectrons deposit the majority of energy emitted by nanoparticles, over long ranges. However, short-range energy deposition is dominated by Auger electrons. While total energy deposition increases with atomic number, short-range energy deposition has a more complex behaviour, with local maxima around germanium ($Z=32$) and gadolinium ($Z=64$). For megavoltage radiation, Compton electrons deposit the majority of energy, but short-range depositions are dominated by interactions with secondary electrons. As a Result, energy deposition following ionising events following Linac irradiation is largely independent of atomic number. When analysed through the Local Effect Model, these effects translate into significant variations in predicted cell killing with atomic number for keV exposures, but comparatively limited effects for megavoltage exposures.

Conclusions:

Although heavier elements typically lead to greater increases in dose within target volumes, on the nanometre scale effects are typically dominated by low-energy secondary electrons, whose distribution has a complex relationship with both nanoparticle composition and beam energy. These results suggest that maximum radiosensitization may not necessarily be achieved through maximizing atomic number, but rather a balance between overall interaction cross-section and local dose distribution. The different behaviours seen when comparing keV and MV behaviours may also provide future mechanisms for separating physical and biological mechanisms of nanoparticle sensitisation, a key step in their development as a potential therapeutic agent.

